US009298485B2

(12) **United States Patent**
Bragstad et al.

(10) **Patent No.: US 9,298,485 B2**
(45) **Date of Patent: Mar. 29, 2016**

(54) **MAINTAINING VIRTUAL MACHINES FOR CLOUD-BASED OPERATORS IN A STREAMING APPLICATION IN A READY STATE**

(71) Applicant: **International Business Machines Corporation**, Armonk, NY (US)

(72) Inventors: **Lance Bragstad**, Pine Island, MN (US); **Michael J. Branson**, Rochester, MN (US); **Bin Cao**, Rochester, MN (US); **James E. Carey**, Rochester, MN (US); **Mathew R. Odden**, Rochester, MN (US)

(73) Assignee: **International Business Machines Corporation**, Armonk, NY (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 205 days.

(21) Appl. No.: **14/084,188**

(22) Filed: **Nov. 19, 2013**

(65) **Prior Publication Data**

US 2015/0142952 A1 May 21, 2015

(51) **Int. Cl.**

G06F 9/455 (2006.01)
H04L 12/26 (2006.01)
H04L 29/06 (2006.01)
H04L 12/24 (2006.01)

(52) **U.S. Cl.**

CPC ***G06F 9/455*** (2013.01); ***H04L 41/5019*** (2013.01); ***H04L 43/0876*** (2013.01); ***H04L 43/16*** (2013.01); ***H04L 65/60*** (2013.01)

(58) **Field of Classification Search**

CPC . G06F 9/5077; G06F 9/5083; H04L 43/0811; H04L 43/0882

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

7,272,820	B2 *	9/2007	Klianev	717/109
7,415,704	B2	8/2008	Schmidt et al.	
8,359,594	B1	1/2013	Davidson et al.	
8,694,994	B1 *	4/2014	Vincent et al.	718/1
9,015,708	B2 *	4/2015	Choudhury et al.	718/1
9,021,477	B2 *	4/2015	Choudhury et al.	718/1
9,027,024	B2 *	5/2015	Mick et al.	718/1
2010/0058342	A1	3/2010	Machida	
2012/0179809	A1 *	7/2012	Barsness et al.	709/224
2012/0304192	A1 *	11/2012	Grove et al.	718/105
2013/0007744	A1	1/2013	Arasaratnam	
2013/0117359	A1	5/2013	Husain et al.	
2013/0173587	A1 *	7/2013	Imaki et al.	707/713
2013/0179574	A1	7/2013	Calder et al.	
2013/0297802	A1 *	11/2013	Laribi et al.	709/226
2014/0068577	A1 *	3/2014	Gedik et al.	717/143
2014/0068578	A1 *	3/2014	Gedik et al.	717/143
2014/0196017	A1 *	7/2014	Halim et al.	717/149
2014/0201642	A1 *	7/2014	Vicat-Blanc	715/736
2014/0215077	A1 *	7/2014	Soudan et al.	709/226

(Continued)

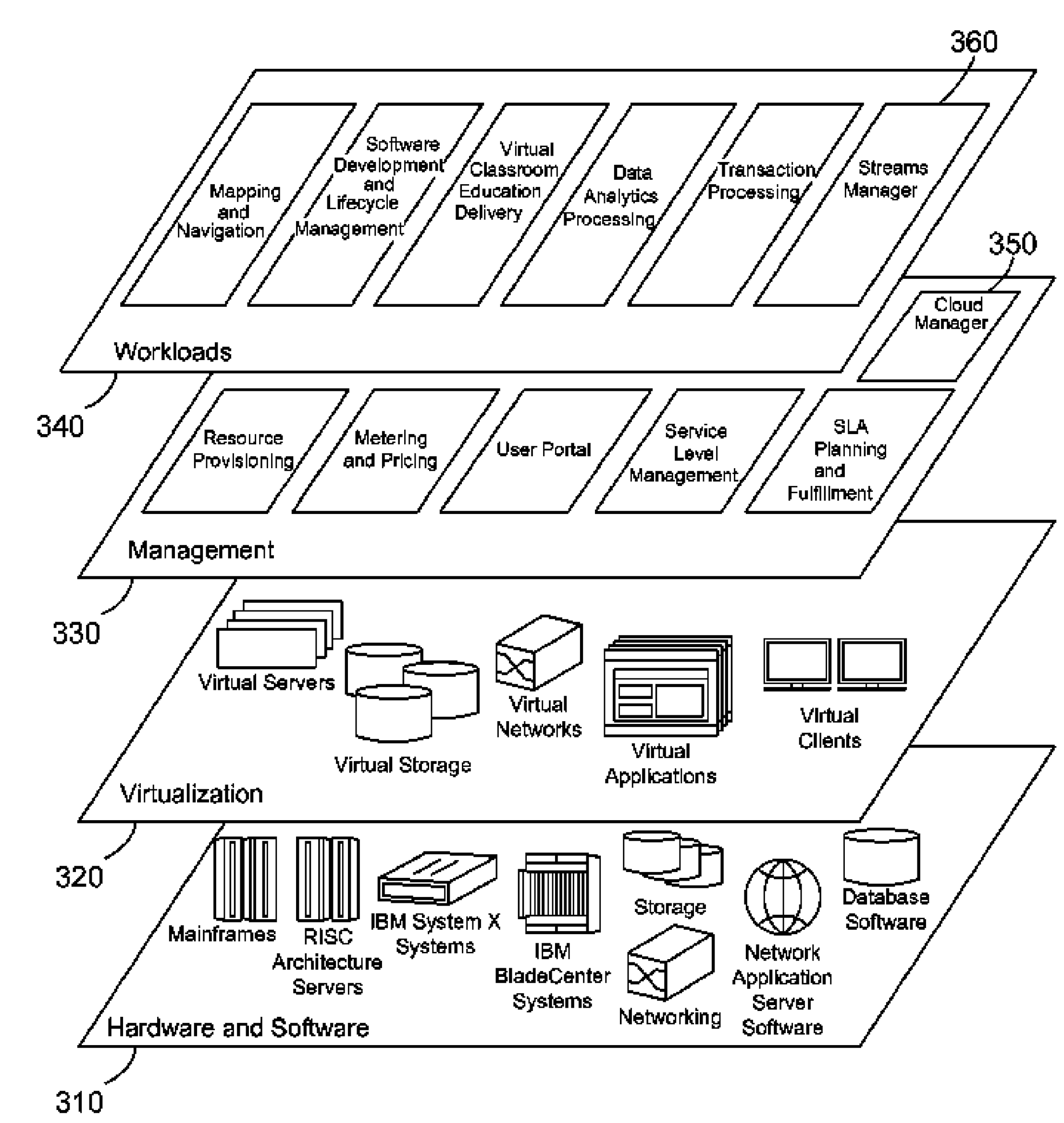
Primary Examiner — Shirley Zhang

(74) *Attorney, Agent, or Firm* — Martin & Associates, LLC; Derek P. Martin

(57) **ABSTRACT**

A streams manager monitors performance of a streaming application, and when the performance needs to be improved, the streams manager automatically requests virtual machines from a cloud manager. The cloud manager provisions one or more virtual machines in a cloud with the specified streams infrastructure and streams application components. The streams manager then modifies the flow graph so one or more portions of the streaming application are hosted by the virtual machines in the cloud. When performance of the streaming application indicates a virtual machine is no longer needed, the virtual machine is maintained and placed in a ready state so it can be quickly used as needed in the future without the overhead of deploying a new virtual machine.

9 Claims, 9 Drawing Sheets



(56) **References Cited**

U.S. PATENT DOCUMENTS

2014/0280595	A1*	9/2014	Mani et al.	709/204
2015/0127807	A1*	5/2015	Billore et al.	709/224
2015/0127815	A1*	5/2015	Billore et al.	709/224
2015/0128131	A1*	5/2015	Cao et al.	718/1
2015/0142951	A1*	5/2015	Bragstad et al.	709/224
2015/0142952	A1*	5/2015	Bragstad et al.	709/224
2015/0142956	A1*	5/2015	Bragstad et al.	709/224
2015/0143365	A1*	5/2015	Bragstad et al.	718/1
2015/0205627	A1*	7/2015	Cao et al.	718/1
2015/0207749	A1*	7/2015	Cao et al.	718/1

* cited by examiner

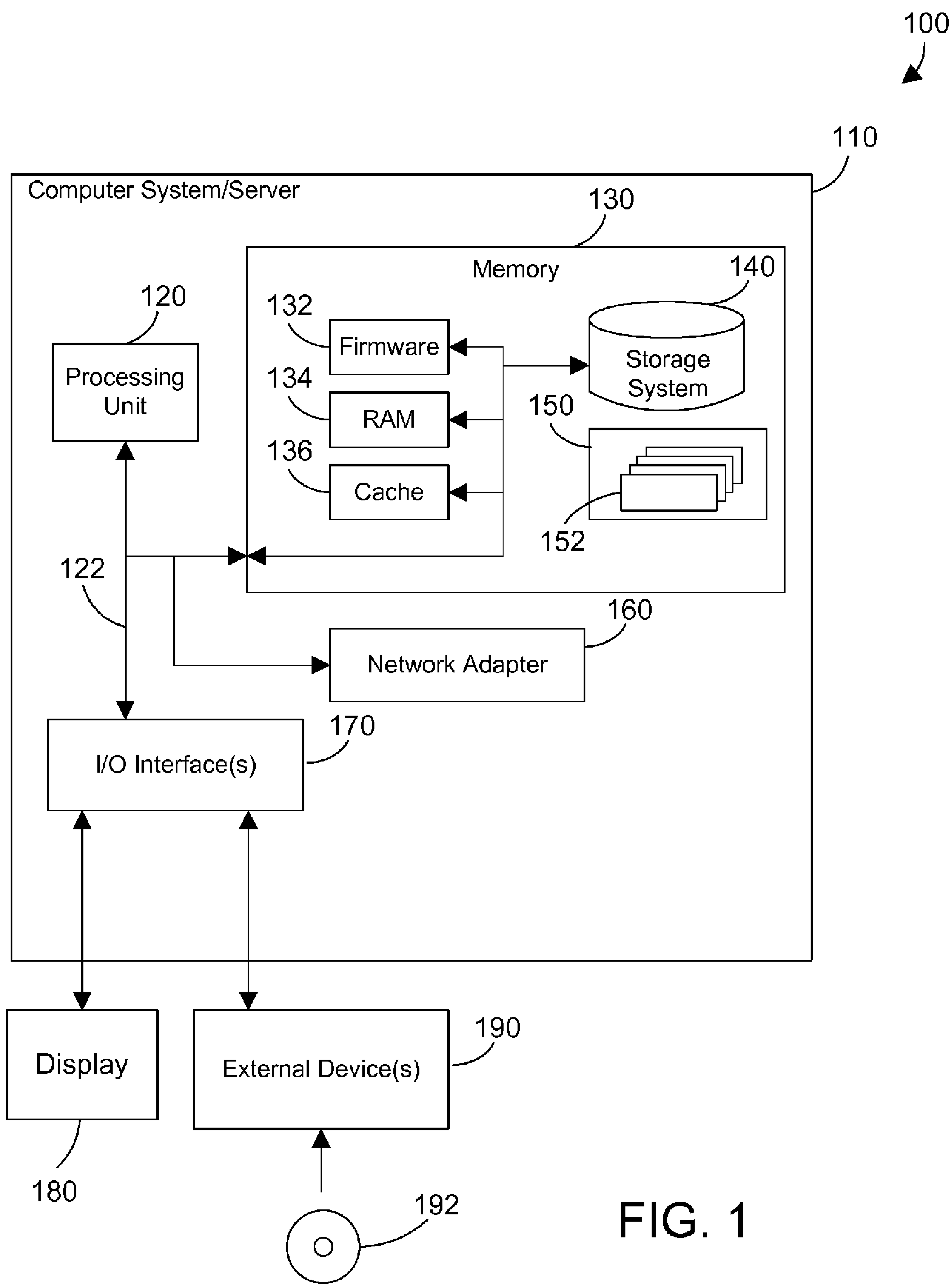

100
110
Computer System/Server
130
Memory
140
120
132
Firmware
Storage System
Processing Unit
134
RAM
150
136
Cache
152
122
160
Network Adapter
170
I/O Interface(s)
Display
External Device(s)
190
180
192

FIG. 1

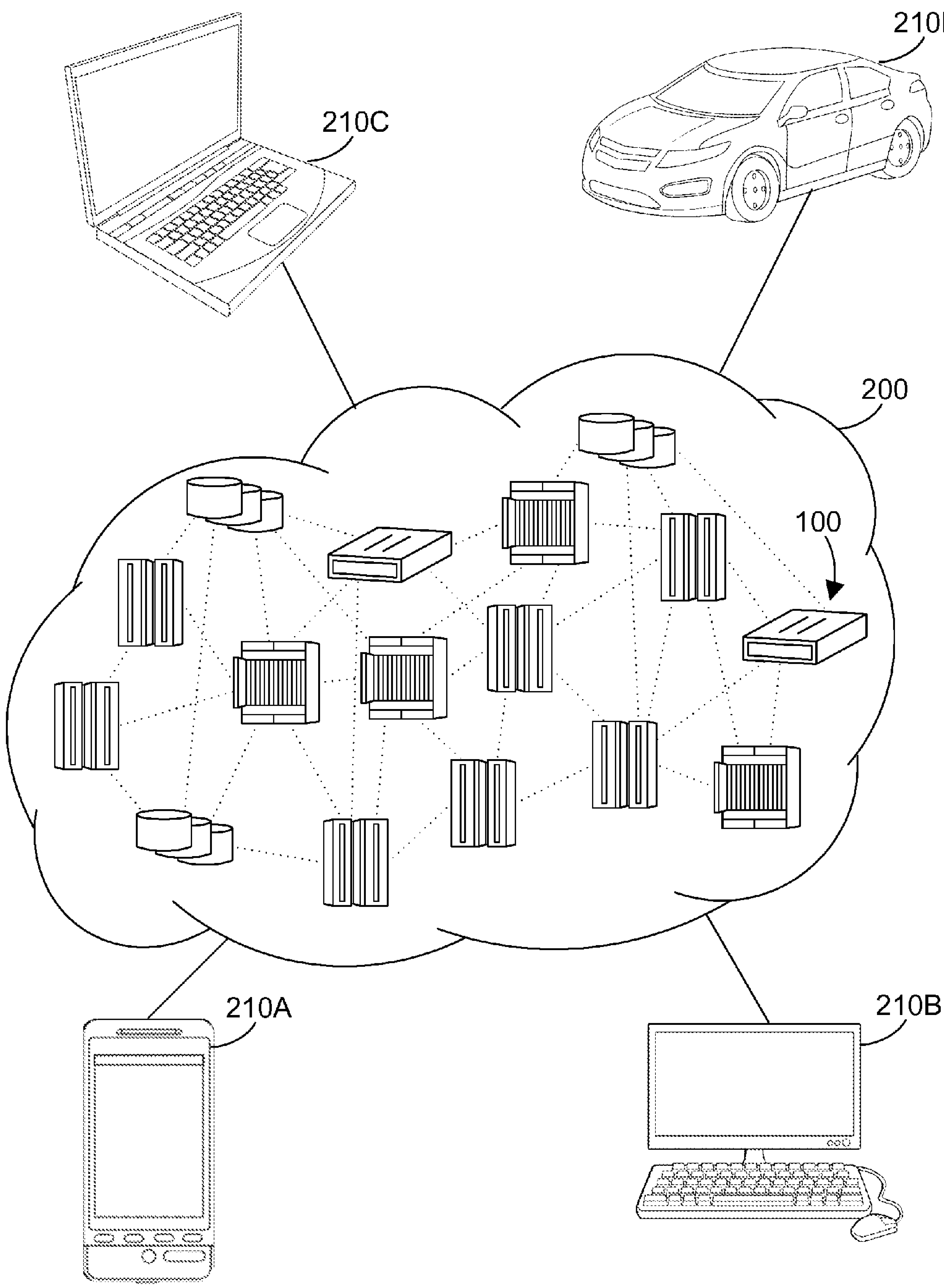


FIG. 2

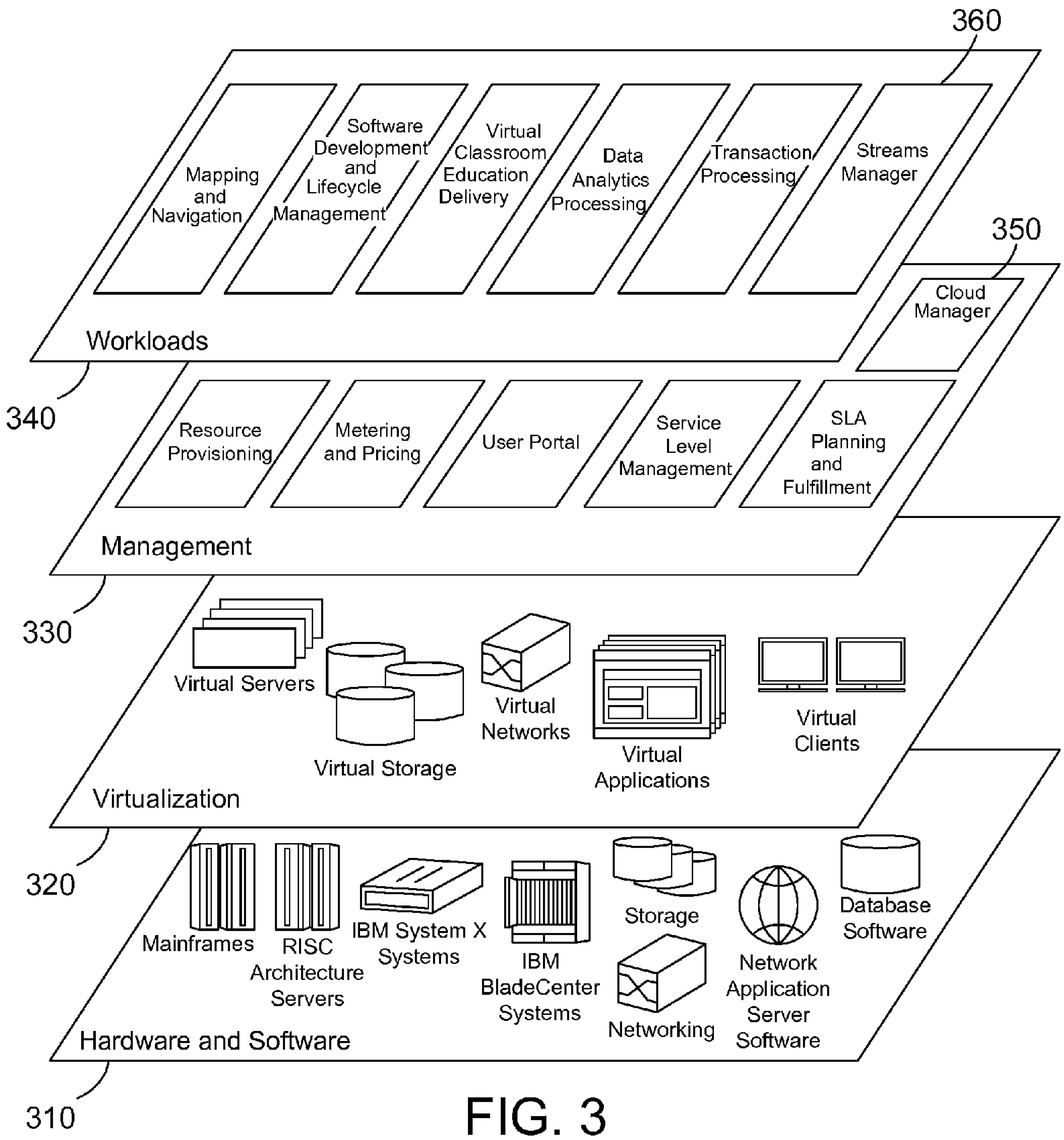

360
Mapping and Navigation
Software Development and Lifecycle Management
Virtual Classroom Education Delivery
Data Analytics Processing
Transaction Processing
Streams Manager
Workloads
350
Cloud Manager
340
Resource Provisioning
Metering and Pricing
User Portal
Service Level Management
SLA Planning and Fulfillment
Management
330
Virtual Servers
Virtual Storage
Virtual Networks
Virtual Applications
Virtual Clients
Virtualization
320
Mainframes
RISC Architecture Servers
IBM System X Systems
IBM BladeCenter Systems
Storage
Networking
Network Application Server Software
Database Software
Hardware and Software
310

FIG. 3

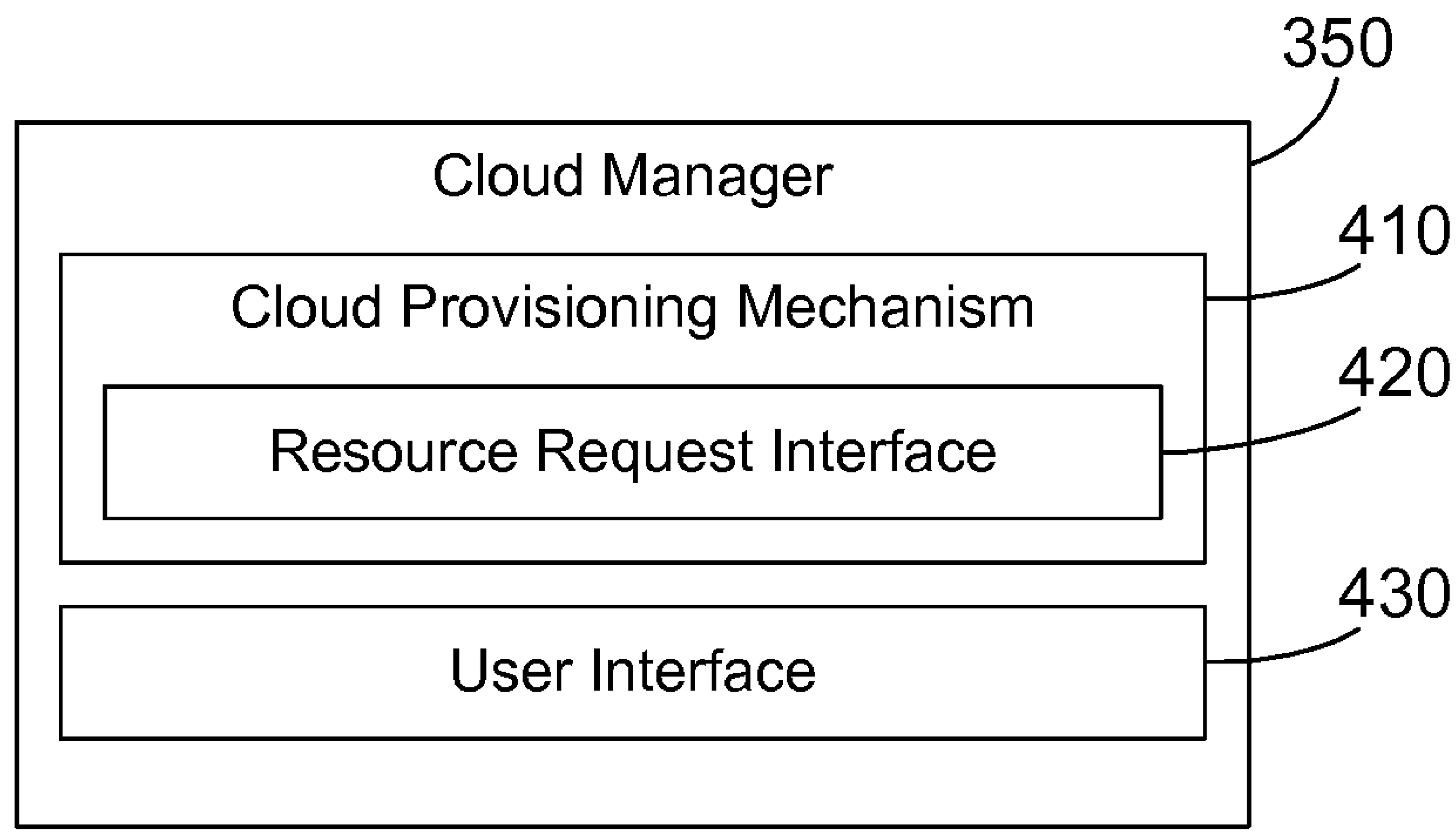

350
Cloud Manager
410
Cloud Provisioning Mechanism
420
Resource Request Interface
430
User Interface

FIG. 4

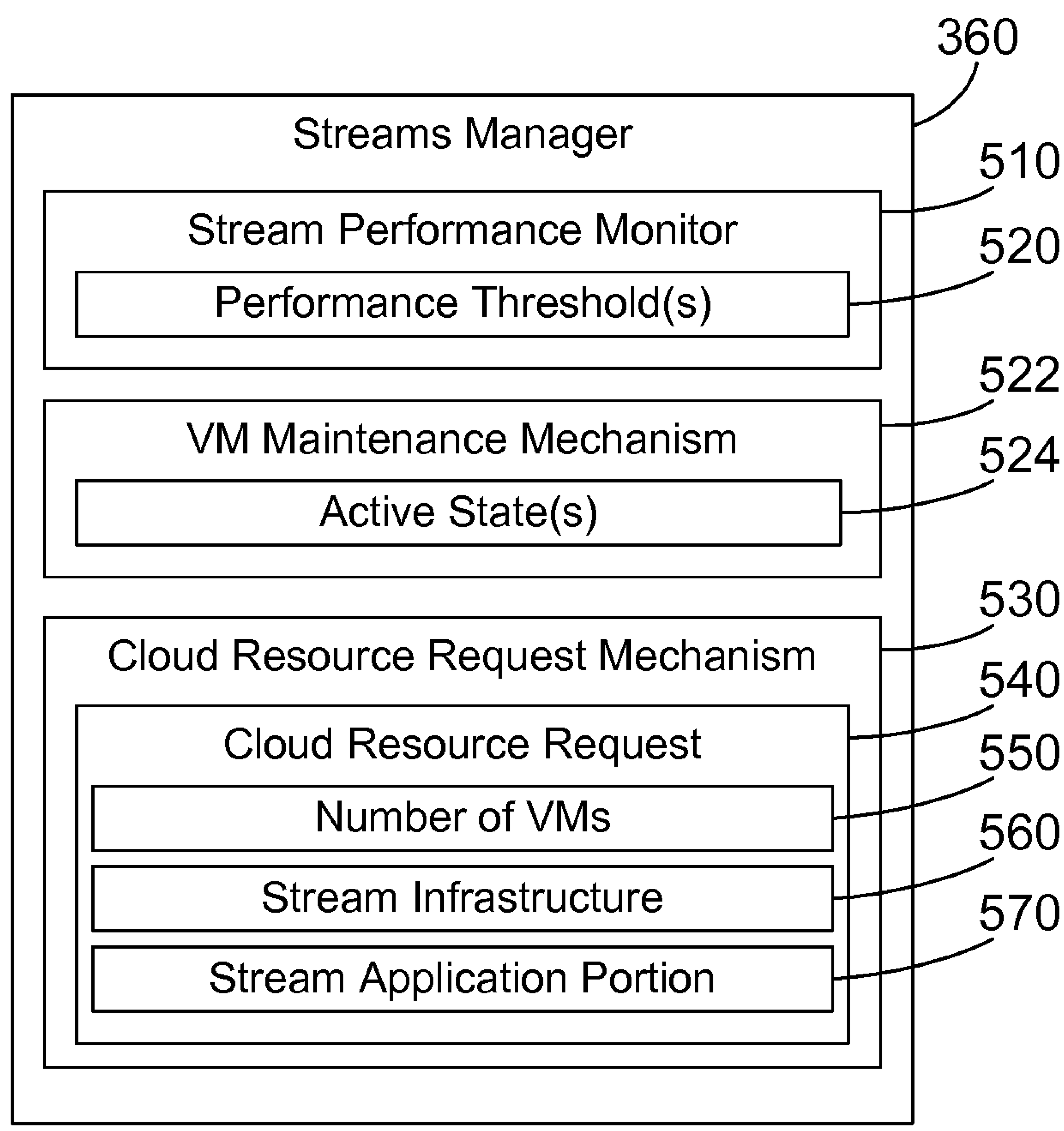

360
Streams Manager
510
Stream Performance Monitor
520
Performance Threshold(s)
522
VM Maintenance Mechanism
524
Active State(s)
530
Cloud Resource Request Mechanism
540
Cloud Resource Request
550
Number of VMs
560
Stream Infrastructure
570
Stream Application Portion

FIG. 5

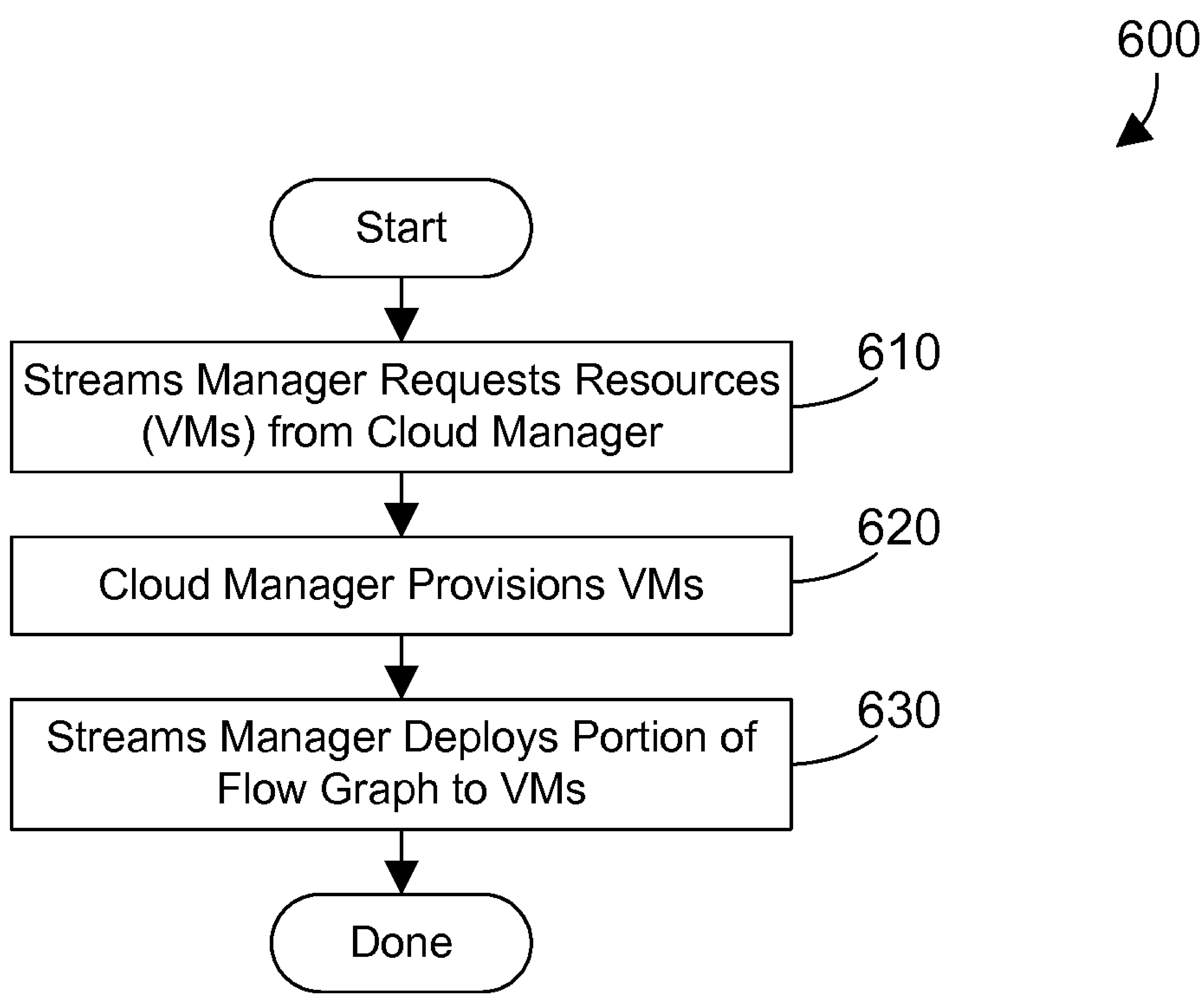

600
Start
Streams Manager Requests Resources (VMs) from Cloud Manager
610
Cloud Manager Provisions VMs
620
Streams Manager Deploys Portion of Flow Graph to VMs
630
Done

FIG. 6

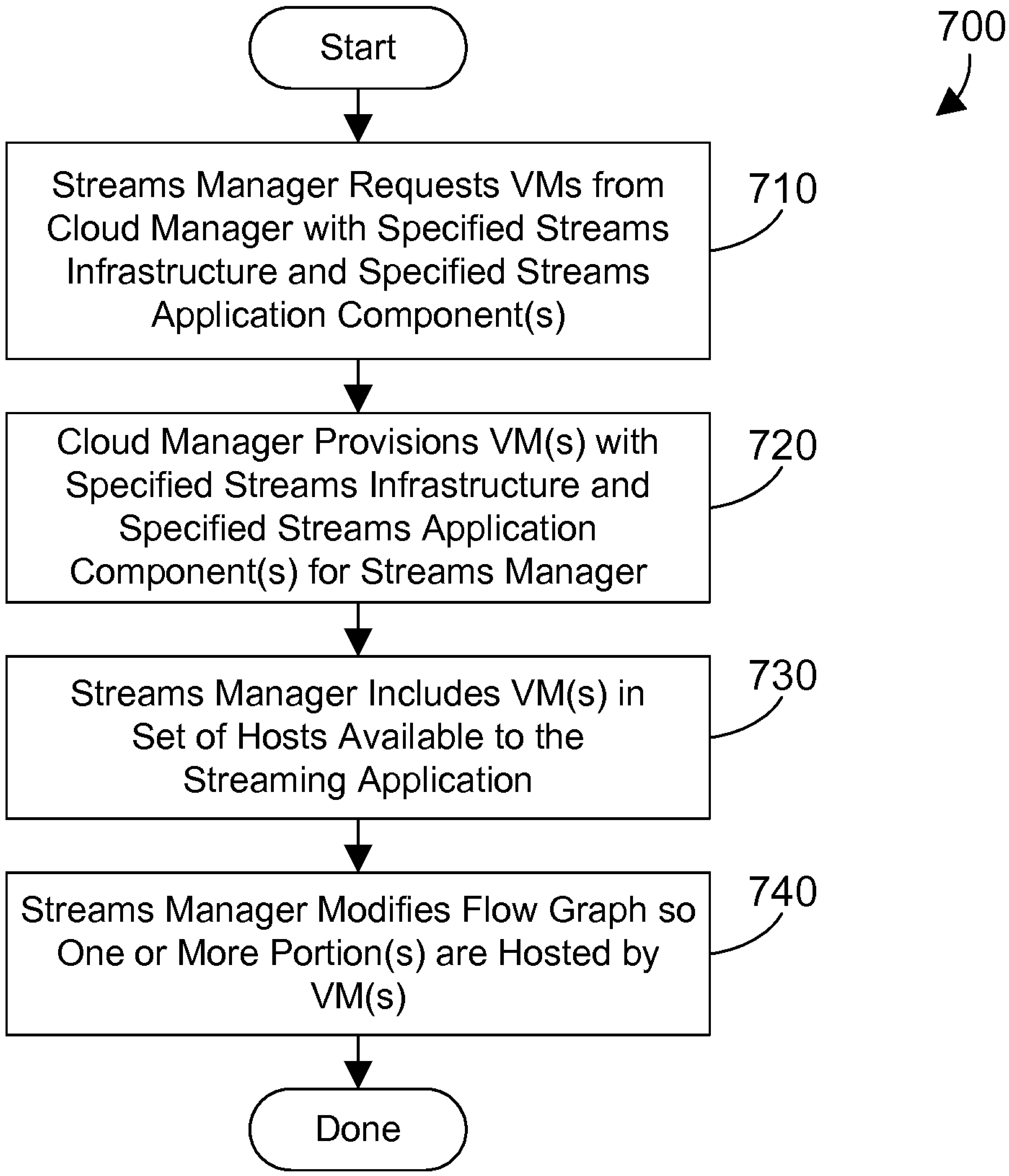

700
Start
Streams Manager Requests VMs from Cloud Manager with Specified Streams Infrastructure and Specified Streams Application Component(s)
710
Cloud Manager Provisions VM(s) with Specified Streams Infrastructure and Specified Streams Application Component(s) for Streams Manager
720
Streams Manager Includes VM(s) in Set of Hosts Available to the Streaming Application
730
Streams Manager Modifies Flow Graph so One or More Portion(s) are Hosted by VM(s)
740
Done

FIG. 7

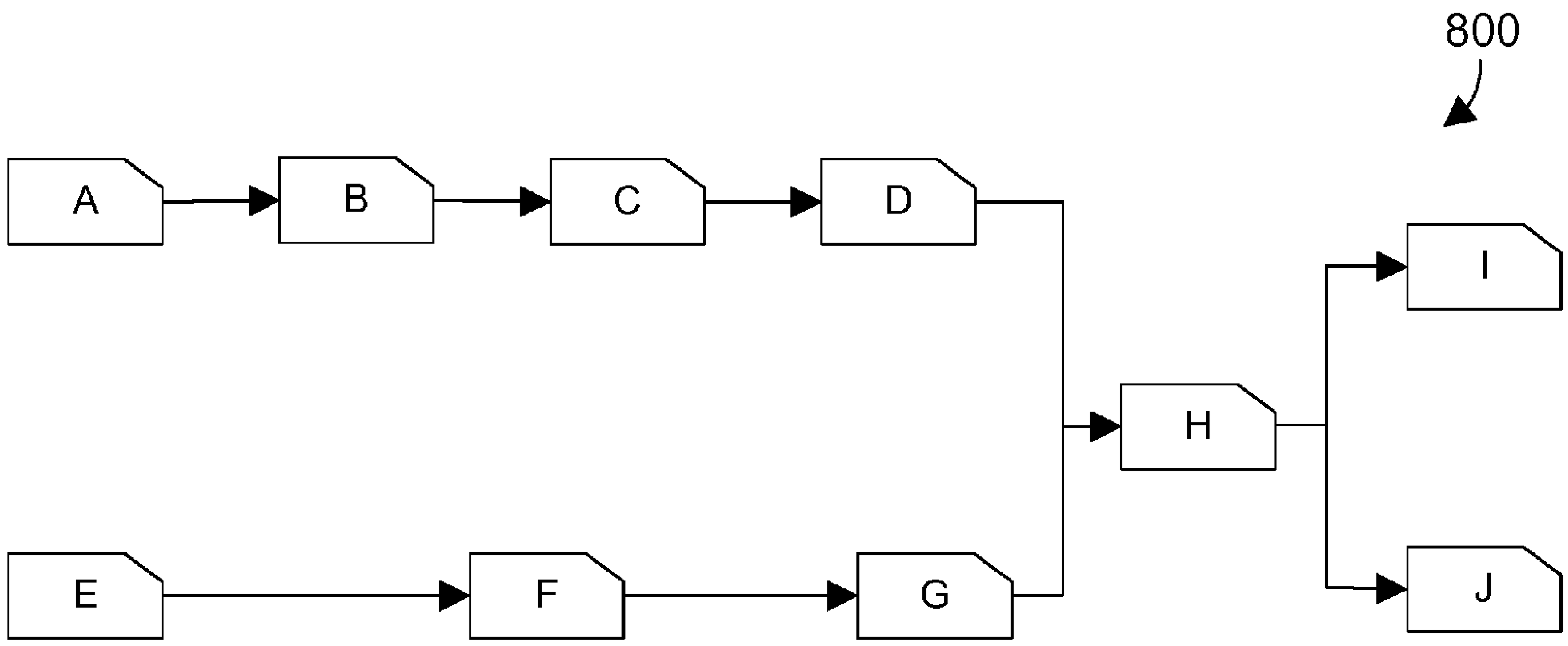


FIG. 8

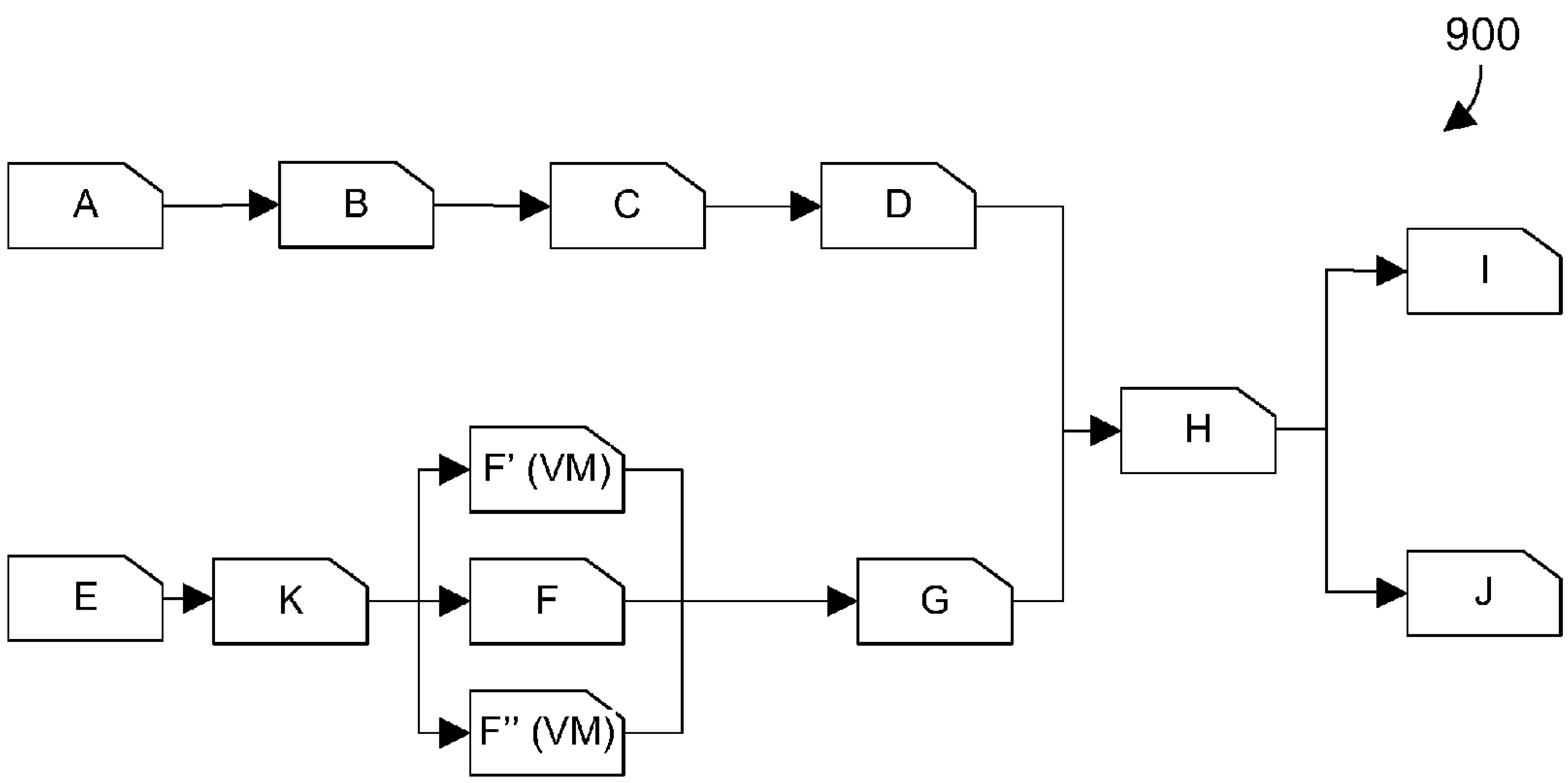


FIG. 9

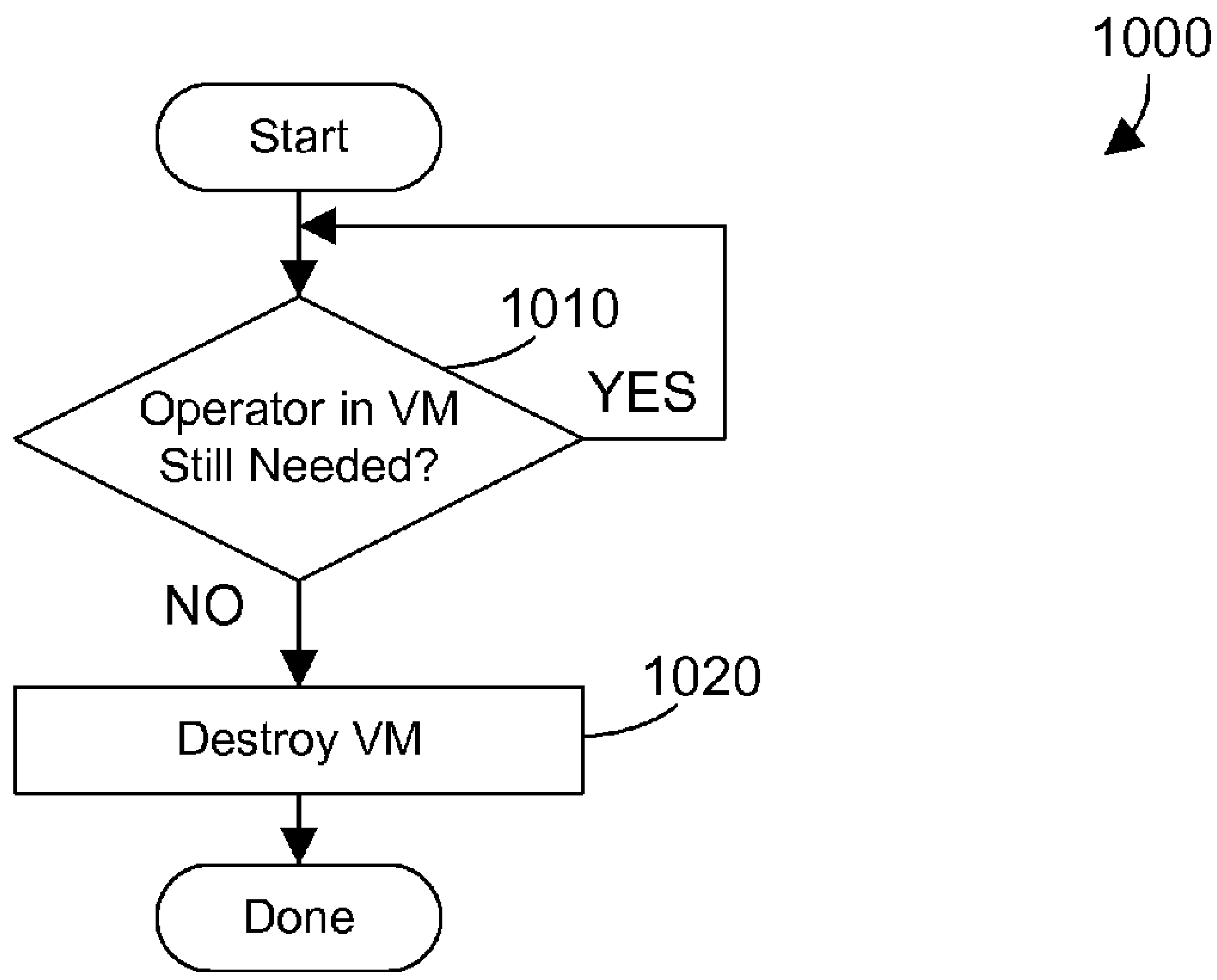


FIG. 10

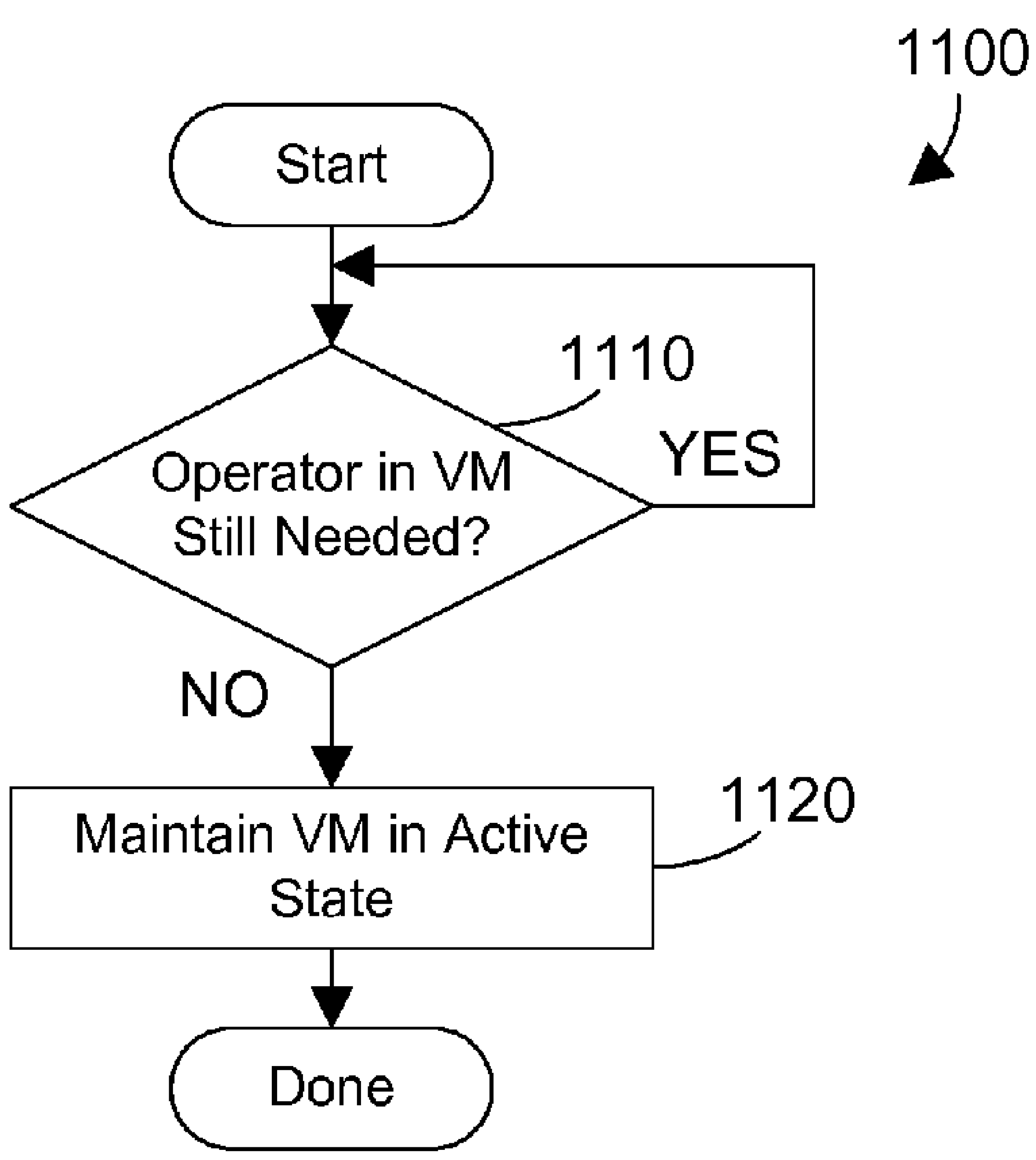


FIG. 11

Active States	
Leave Input and Output Connected to Flow Graph Until VM is Needed Elsewhere	1210
Disconnect Input and Output from Flow Graph	1220
Disconnect Output from Flow Graph	1230

FIG. 12

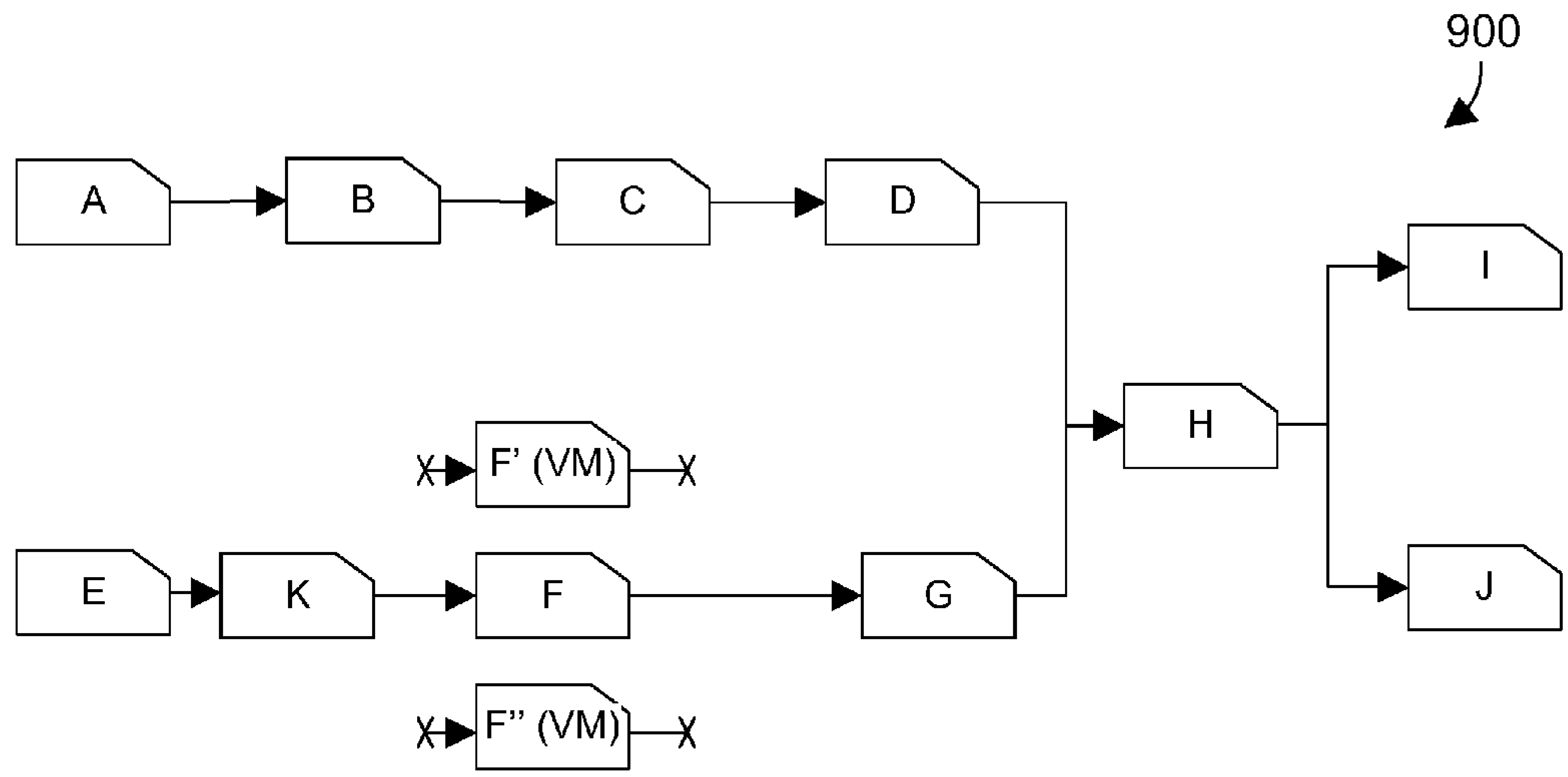


FIG. 13

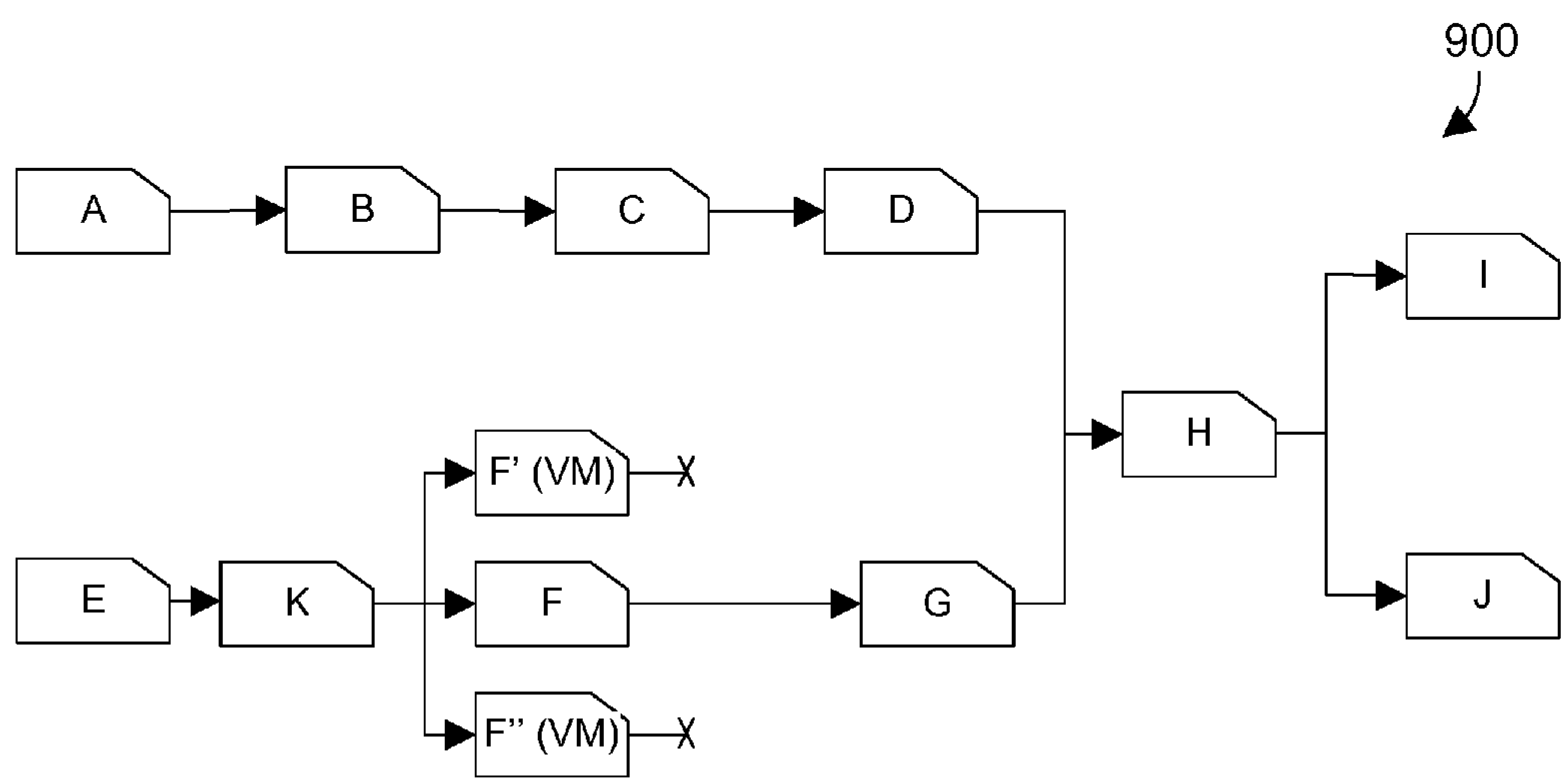


FIG. 14

MAINTAINING VIRTUAL MACHINES FOR CLOUD-BASED OPERATORS IN A STREAMING APPLICATION IN A READY STATE

BACKGROUND

1. Technical Field

This disclosure generally relates to streaming applications, and more specifically relates to enhancing performance of a streaming application using cloud resources.

2. Background Art

Streaming applications are known in the art, and typically include multiple operators coupled together in a flow graph that process streaming data in near real-time. An operator typically takes in streaming data in the form of data tuples, operates on the tuples in some fashion, and outputs the processed tuples to the next operator. Streaming applications are becoming more common due to the high performance that can be achieved from near real-time processing of streaming data.

Many streaming applications require significant computer resources, such as processors and memory, to provide the desired near real-time processing of data. However, the workload of a streaming application can vary greatly over time. Allocating on a permanent basis computer resources to a streaming application that would assure the streaming application would always function as desired (i.e., during peak demand) would mean many of those resources would sit idle when the streaming application is processing a workload significantly less than its maximum. Furthermore, what constitutes peak demand at one point in time can be exceeded as the usage of the streaming application increases. For a dedicated system that runs a streaming application, an increase in demand may require a corresponding increase in hardware resources to meet that demand.

BRIEF SUMMARY

A streams manager monitors performance of a streaming application, and when the performance needs to be improved, the streams manager automatically requests virtual machines from a cloud manager. The cloud manager provisions one or more virtual machines in a cloud with the specified streams infrastructure and streams application components. The streams manager then modifies the flow graph so one or more portions of the streaming application are hosted by the virtual machines in the cloud. When performance of the streaming application indicates a virtual machine is no longer needed, the virtual machine is maintained and placed in a ready state so it can be quickly used as needed in the future without the overhead of deploying a new virtual machine.

The foregoing and other features and advantages will be apparent from the following more particular description, as illustrated in the accompanying drawings.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING(S)

The disclosure will be described in conjunction with the appended drawings, where like designations denote like elements, and:

FIG. **1** is a block diagram of a cloud computing node;

FIG. **2** is a block diagram of a cloud computing environment;

FIG. **3** is a block diagram of abstraction model layers;

FIG. **4** is a block diagram showing some features of a cloud manager;

FIG. **5** is a block diagram showing some features of a streams manager;

FIG. **6** is a flow diagram of a method for a streams manager to request and receive from a cloud manager virtual machines to improve performance of a streaming application;

FIG. **7** is a flow diagram of a specific method in accordance with method **600** in FIG. **6** for a streams manager to request and receive from a cloud manager virtual machines to improve performance of a streaming application;

FIG. **8** is a block diagram of one specific example of a streaming application;

FIG. **9** is a block diagram showing the streaming application in FIG. **8** after the addition of two virtual machines provisioned from a cloud;

FIG. **10** is a flow diagram of a method for destroying a virtual machine that implements an operator in a flow graph when the operator is no longer needed;

FIG. **11** is a flow diagram of a method for maintaining a virtual machine in an active state when the operator in the virtual machine is no longer needed;

FIG. **12** is a table that lists examples of active states for a virtual machine;

FIG. **13** is a block diagram of one specific example of the streaming application in FIG. **9** after the inputs and outputs of the two virtual machines that implement operators F' and F" have been disconnected from the flow graph, keeping the virtual machines for operators F' and F" in a ready state; and

FIG. **14** is a block diagram of one specific example of the streaming application in FIG. **9** after the outputs of the two virtual machines that implement operators F' and F" have been disconnected from the flow graph, keeping the virtual machines for operators F' and F" in a ready state.

DETAILED DESCRIPTION

The disclosure and claims herein relate to a streams manager that monitors performance of a streaming application, and when the performance needs to be improved, the streams manager automatically requests virtual machines from a cloud manager. The cloud manager provisions one or more virtual machines in a cloud with the specified streams infrastructure and streams application components. The streams manager then modifies the flow graph so one or more portions of the streaming application are hosted by the virtual machines in the cloud. When performance of the streaming application indicates a virtual machine is no longer needed, the virtual machine is maintained and placed in a ready state so it can be quickly used as needed in the future without the overhead of deploying a new virtual machine.

It is understood in advance that although this disclosure includes a detailed description on cloud computing, implementation of the teachings recited herein are not limited to a cloud computing environment. Rather, embodiments of the present invention are capable of being implemented in conjunction with any other type of computing environment now known or later developed.

Cloud computing is a model of service delivery for enabling convenient, on-demand network access to a shared pool of configurable computing resources (e.g., networks, network bandwidth, servers, processing, memory, storage, applications, virtual machines, and services) that can be rapidly provisioned and released with minimal management effort or interaction with a provider of the service. This cloud model may include at least five characteristics, at least three service models, and at least four deployment models.

Characteristics are as follows:

On-demand self-service: a cloud consumer can unilaterally provision computing capabilities, such as server time and network storage, as needed automatically without requiring human interaction with the service's provider.

Broad network access: capabilities are available over a network and accessed through standard mechanisms that promote use by heterogeneous thin or thick client platforms (e.g., mobile phones, laptops, and PDAs).

Resource pooling: the provider's computing resources are pooled to serve multiple consumers using a multi-tenant model, with different physical and virtual resources dynamically assigned and reassigned according to demand. There is a sense of location independence in that the consumer generally has no control or knowledge over the exact location of the provided resources but may be able to specify location at a higher level of abstraction (e.g., country, state, or datacenter).

Rapid elasticity: capabilities can be rapidly and elastically provisioned, in some cases automatically, to quickly scale out and rapidly released to quickly scale in. To the consumer, the capabilities available for provisioning often appear to be unlimited and can be purchased in any quantity at any time.

Measured service: cloud systems automatically control and optimize resource use by leveraging a metering capability at some level of abstraction appropriate to the type of service (e.g., storage, processing, bandwidth, and active user accounts). Resource usage can be monitored, controlled, and reported providing transparency for both the provider and consumer of the utilized service.

Service Models are as follows:

Software as a Service (SaaS): the capability provided to the consumer is to use the provider's applications running on a cloud infrastructure. The applications are accessible from various client devices through a thin client interface such as a web browser (e.g., web-based e-mail). The consumer does not manage or control the underlying cloud infrastructure including network, servers, operating systems, storage, or even individual application capabilities, with the possible exception of limited user-specific application configuration settings.

Platform as a Service (PaaS): the capability provided to the consumer is to deploy onto the cloud infrastructure consumer-created or acquired applications created using programming languages and tools supported by the provider. The consumer does not manage or control the underlying cloud infrastructure including networks, servers, operating systems, or storage, but has control over the deployed applications and possibly application hosting environment configurations.

Infrastructure as a Service (IaaS): the capability provided to the consumer is to provision processing, storage, networks, and other fundamental computing resources where the consumer is able to deploy and run arbitrary software, which can include operating systems and applications. The consumer does not manage or control the underlying cloud infrastructure but has control over operating systems, storage, deployed applications, and possibly limited control of select networking components (e.g., host firewalls).

Deployment Models are as follows:

Private cloud: the cloud infrastructure is operated solely for an organization. It may be managed by the organization or a third party and may exist on-premises or off-premises.

Community cloud: the cloud infrastructure is shared by several organizations and supports a specific community that has shared concerns (e.g., mission, security requirements, policy, and compliance considerations). It may be managed by the organizations or a third party and may exist on-premises or off-premises.

Public cloud: the cloud infrastructure is made available to the general public or a large industry group and is owned by an organization selling cloud services.

Hybrid cloud: the cloud infrastructure is a composition of two or more clouds (private, community, or public) that remain unique entities but are bound together by standardized or proprietary technology that enables data and application portability (e.g., cloud bursting for loadbalancing between clouds).

A cloud computing environment is service oriented with a focus on statelessness, low coupling, modularity, and semantic interoperability. At the heart of cloud computing is an infrastructure comprising a network of interconnected nodes.

Referring now to FIG. **1**, a block diagram of an example of a cloud computing node is shown. Cloud computing node **100** is only one example of a suitable cloud computing node and is not intended to suggest any limitation as to the scope of use or functionality of embodiments of the invention described herein. Regardless, cloud computing node **100** is capable of being implemented and/or performing any of the functionality set forth hereinabove.

In cloud computing node **100** there is a computer system/server **110**, which is operational with numerous other general purpose or special purpose computing system environments or configurations. Examples of well-known computing systems, environments, and/or configurations that may be suitable for use with computer system/server **110** include, but are not limited to, personal computer systems, server computer systems, tablet computer systems, thin clients, thick clients, handheld or laptop devices, multiprocessor systems, microprocessor-based systems, set top boxes, programmable consumer electronics, network PCs, minicomputer systems, mainframe computer systems, and distributed cloud computing environments that include any of the above systems or devices, and the like.

Computer system/server **110** may be described in the general context of computer system executable instructions, such as program modules, being executed by a computer system. Generally, program modules may include routines, programs, objects, components, logic, data structures, and so on that perform particular tasks or implement particular abstract data types. Computer system/server **110** may be practiced in distributed cloud computing environments where tasks are performed by remote processing devices that are linked through a communications network. In a distributed cloud computing environment, program modules may be located in both local and remote computer system storage media including memory storage devices.

As shown in FIG. **1**, computer system/server **110** in cloud computing node **100** is shown in the form of a general-purpose computing device. The components of computer system/server **110** may include, but are not limited to, one or more processors or processing units **120**, a system memory **130**, and a bus **122** that couples various system components including system memory **130** to processing unit **120**.

Bus **122** represents one or more of any of several types of bus structures, including a memory bus or memory controller, a peripheral bus, an accelerated graphics port, and a processor or local bus using any of a variety of bus architectures. By way of example, and not limitation, such architectures include Industry Standard Architecture (ISA) bus, Micro Channel Architecture (MCA) bus, Enhanced ISA (EISA) bus, Video Electronics Standards Association (VESA) local bus, and Peripheral Component Interconnect (PCI) bus.

Computer system/server **110** typically includes a variety of computer system readable media. Such media may be any available media that is accessible by computer system/server **110**, and it includes both volatile and non-volatile media, removable and non-removable media. An example of removable media is shown in FIG. **1** to include a Digital Video Disc (DVD) **192**.

System memory **130** can include computer system readable media in the form of volatile or non-volatile memory, such as firmware **132**. Firmware **132** provides an interface to the hardware of computer system/server **110**. System memory **130** can also include computer system readable media in the form of volatile memory, such as random access memory (RAM) **134** and/or cache memory **136**. Computer system/server **110** may further include other removable/non-removable, volatile/non-volatile computer system storage media. By way of example only, storage system **140** can be provided for reading from and writing to a non-removable, non-volatile magnetic media (not shown and typically called a "hard drive"). Although not shown, a magnetic disk drive for reading from and writing to a removable, non-volatile magnetic disk (e.g., a "floppy disk"), and an optical disk drive for reading from or writing to a removable, non-volatile optical disk such as a CD-ROM, DVD-ROM or other optical media can be provided. In such instances, each can be connected to bus **122** by one or more data media interfaces. As will be further depicted and described below, memory **130** may include at least one program product having a set (e.g., at least one) of program modules that are configured to carry out the functions described in more detail below.

Program/utility **150**, having a set (at least one) of program modules **152**, may be stored in memory **130** by way of example, and not limitation, as well as an operating system, one or more application programs, other program modules, and program data. Each of the operating system, one or more application programs, other program modules, and program data or some combination thereof, may include an implementation of a networking environment. Program modules **152** generally carry out the functions and/or methodologies of embodiments of the invention as described herein.

Computer system/server **110** may also communicate with one or more external devices **190** such as a keyboard, a pointing device, a display **180**, a disk drive, etc.; one or more devices that enable a user to interact with computer system/server **110**; and/or any devices (e.g., network card, modem, etc.) that enable computer system/server **110** to communicate with one or more other computing devices. Such communication can occur via Input/Output (I/O) interfaces **170**. Still yet, computer system/server **110** can communicate with one or more networks such as a local area network (LAN), a general wide area network (WAN), and/or a public network (e.g., the Internet) via network adapter **160**. As depicted, network adapter **160** communicates with the other components of computer system/server **110** via bus **122**. It should be understood that although not shown, other hardware and/or software components could be used in conjunction with computer system/server **110**. Examples, include, but are not limited to: microcode, device drivers, redundant processing units, external disk drive arrays, Redundant Array of Independent Disk (RAID) systems, tape drives, data archival storage systems, etc.

Referring now to FIG. **2**, illustrative cloud computing environment **200** is depicted. As shown, cloud computing environment **200** comprises one or more cloud computing nodes **100** with which local computing devices used by cloud consumers, such as, for example, personal digital assistant (PDA) or cellular telephone **210**A, desktop computer **210**B, laptop computer **210**C, and/or automobile computer system **210**N may communicate. Nodes **100** may communicate with one another. They may be grouped (not shown) physically or virtually, in one or more networks, such as Private, Community, Public, or Hybrid clouds as described hereinabove, or a combination thereof. This allows cloud computing environment **200** to offer infrastructure, platforms and/or software as services for which a cloud consumer does not need to maintain resources on a local computing device. It is understood that the types of computing devices **210**A-N shown in FIG. **2** are intended to be illustrative only and that computing nodes **100** and cloud computing environment **200** can communicate with any type of computerized device over any type of network and/or network addressable connection (e.g., using a web browser).

Referring now to FIG. **3**, a set of functional abstraction layers provided by cloud computing environment **200** in FIG. **2** is shown. It should be understood in advance that the components, layers, and functions shown in FIG. **3** are intended to be illustrative only and the disclosure and claims are not limited thereto. As depicted, the following layers and corresponding functions are provided.

Hardware and software layer **310** includes hardware and software components. Examples of hardware components include mainframes, in one example IBM System z systems; RISC (Reduced Instruction Set Computer) architecture based servers, in one example IBM System p systems; IBM System x systems; IBM BladeCenter systems; storage devices; networks and networking components. Examples of software components include network application server software, in one example IBM WebSphere® application server software; and database software, in one example IBM DB2® database software. IBM, System z, System p, System x, BladeCenter, WebSphere, and DB2 are trademarks of International Business Machines Corporation registered in many jurisdictions worldwide.

Virtualization layer **320** provides an abstraction layer from which the following examples of virtual entities may be provided: virtual servers; virtual storage; virtual networks, including virtual private networks; virtual applications and operating systems; and virtual clients.

In one example, management layer **330** may provide the functions described below. Resource provisioning provides dynamic procurement of computing resources and other resources that are utilized to perform tasks within the cloud computing environment. Metering and Pricing provide cost tracking as resources are utilized within the cloud computing environment, and billing or invoicing for consumption of these resources. In one example, these resources may comprise application software licenses. Security provides identity verification for cloud consumers and tasks, as well as protection for data and other resources. User portal provides access to the cloud computing environment for consumers and system administrators. Service level management provides cloud computing resource allocation and management such that required service levels are met. Service Level Agreement (SLA) planning and fulfillment provide pre-arrangement for, and procurement of, cloud computing resources for which a future requirement is anticipated in accordance with an SLA. A cloud manager **350** is representative of a cloud manager as described in more detail below. While the cloud manager **350** is shown in FIG. **3** to reside in the management layer **330**, cloud manager **350** can span all of the levels shown in FIG. **3**, as discussed in detail below.

Workloads layer **340** provides examples of functionality for which the cloud computing environment may be utilized. Examples of workloads and functions which may be provided from this layer include: mapping and navigation; software development and lifecycle management; virtual classroom education delivery; data analytics processing; transaction processing; and a streams manager **360**, as discussed in more detail below.

As will be appreciated by one skilled in the art, aspects of this disclosure may be embodied as a system, method or computer program product. Accordingly, aspects may take the form of an entirely hardware embodiment, an entirely software embodiment (including firmware, resident software, micro-code, etc.) or an embodiment combining software and hardware aspects that may all generally be referred to herein as a "circuit," "module" or "system." Furthermore, aspects of the present invention may take the form of a computer program product embodied in one or more computer readable medium(s) having computer readable program code embodied thereon.

Any combination of one or more computer readable medium(s) may be utilized. The computer readable medium may be a computer readable signal medium or a non-transitory computer readable storage medium. A computer readable storage medium may be, for example, but not limited to, an electronic, magnetic, optical, electromagnetic, infrared, or semiconductor system, apparatus, or device, or any suitable combination of the foregoing. More specific examples (a non-exhaustive list) of the computer readable storage medium would include the following: an electrical connection having one or more wires, a portable computer diskette, a hard disk, a random access memory (RAM), a read-only memory (ROM), an erasable programmable read-only memory (EPROM or Flash memory), an optical fiber, a portable compact disc read-only memory (CD-ROM), an optical storage device, a magnetic storage device, or any suitable combination of the foregoing. In the context of this document, a computer readable storage medium may be any tangible medium that can contain, or store a program for use by or in connection with an instruction execution system, apparatus, or device.

A computer readable signal medium may include a propagated data signal with computer readable program code embodied therein, for example, in baseband or as part of a carrier wave. Such a propagated signal may take any of a variety of forms, including, but not limited to, electro-magnetic, optical, or any suitable combination thereof. A computer readable signal medium may be any computer readable medium that is not a computer readable storage medium and that can communicate, propagate, or transport a program for use by or in connection with an instruction execution system, apparatus, or device.

Program code embodied on a computer readable medium may be transmitted using any appropriate medium, including but not limited to wireless, wireline, optical fiber cable, RF, etc., or any suitable combination of the foregoing.

Computer program code for carrying out operations for aspects of the present invention may be written in any combination of one or more programming languages, including an object oriented programming language such as Java, Smalltalk, C++ or the like and conventional procedural programming languages, such as the "C" programming language or similar programming languages. The program code may execute entirely on the user's computer, partly on the user's computer, as a stand-alone software package, partly on the user's computer and partly on a remote computer or entirely on the remote computer or server. In the latter scenario, the remote computer may be connected to the user's computer through any type of network, including a local area network (LAN) or a wide area network (WAN), or the connection may be made to an external computer (for example, through the Internet using an Internet Service Provider).

Aspects of the present invention are described below with reference to flowchart illustrations and/or block diagrams of methods, apparatus (systems) and computer program products according to embodiments of the invention. It will be understood that each block of the flowchart illustrations and/or block diagrams, and combinations of blocks in the flowchart illustrations and/or block diagrams, can be implemented by computer program instructions. These computer program instructions may be provided to a processor of a general purpose computer, special purpose computer, or other programmable data processing apparatus to produce a machine, such that the instructions, which execute via the processor of the computer or other programmable data processing apparatus, create means for implementing the functions/acts specified in the flowchart and/or block diagram block or blocks.

These computer program instructions may also be stored in a computer readable medium that can direct a computer, other programmable data processing apparatus, or other devices to function in a particular manner, such that the instructions stored in the computer readable medium produce an article of manufacture including instructions which implement the function/act specified in the flowchart and/or block diagram block or blocks.

The computer program instructions may also be loaded onto a computer, other programmable data processing apparatus, or other devices to cause a series of operational steps to be performed on the computer, other programmable apparatus or other devices to produce a computer implemented process such that the instructions which execute on the computer or other programmable apparatus provide processes for implementing the functions/acts specified in the flowchart and/or block diagram block or blocks.

FIG. **4** shows one suitable example of the cloud manager **350** shown in FIG. **3**. The cloud manager **350** includes a cloud provisioning mechanism **410** that includes a resource request interface **420**. The resource request interface **420** allows a software entity, such as the streams manager **360**, to request virtual machines from the cloud manager **350** without human intervention. The cloud manager **350** also includes a user interface **430** that allows a user to interact with the cloud manager to perform any suitable function, including provisioning of VMs, destruction of VMs, performance analysis of the cloud, etc. The difference between the resource request interface **420** and the user interface **430** is a user must manually use the user interface **430** to perform functions specified by the user, while the resource request interface **420** may be used by a software entity to request provisioning of cloud resources by the cloud mechanism **350** without input from a human user. Of course, cloud manager **350** could include many other features and functions known in the art that are not shown in FIG. **4**.

FIG. **5** shows one suitable example of the streams manager **360** shown in FIG. **3**. The streams manager **360** is software that manages one or more streaming applications, including creating operators and data flow connections between operators in a flow graph that represents a streaming application. The streams manager **360** includes a streams performance monitor **510** with one or more performance thresholds **520**. Performance thresholds **520** can include static thresholds, such as percentage used of current capacity, and can also include any suitable heuristic for measuring performance of a streaming application as a whole or for measuring performance of one or more operators in a streaming application. Performance thresholds **520** may include different thresholds and metrics at the operator level, at the level of a group of operators, and/or at the level of the overall performance of the streaming application. The stream performance monitor **510** monitors performance of a streaming application, and when current performance compared to the one or more performance thresholds **520** indicates current performance needs to be improved, the stream performance monitor **510** communicates the need for resources to the cloud resource request mechanism **530**. The cloud resource request mechanism **530**, in response to the communication from the stream performance monitor, assembles a cloud resource request **540**, which can include information such as a number of VMs to provision **550**, stream infrastructure needed in each VM **560**, and a stream application portion **570** for each VM. Once the cloud resource request **540** is formulated, the streams manager **360** submits the cloud resource request **540** to a cloud manager, such as cloud manager **350** shown in FIGS. **3** and **4**.

The streams manager **360** also includes a VM maintenance mechanism **522** that can maintain one or more VMs used to implement one or more operators in a flow graph in one or more active states **524** instead of destroying a VM when its operator is no longer needed. By maintaining a VM in an active state, the VM is available for deployment later implementing the same operator at the same location in the flow graph with very little work, or the VM can be deployed to a different part of the flow graph implementing a different operator with a little more work, but still significantly less work than provisioning and deploying a new VM. With VMs available and maintained in a ready state, the streams manager **360** can respond much more quickly to changing conditions, thereby increasing the performance of the streaming application managed by the streams manager **360**.

As stated above, when the stream performance monitor **510** determines current performance needs to be improved, the stream performance monitor **510** communicates the need for resources to the cloud resource request mechanism **530** using a cloud resource request **540**. The cloud resource request **540** can be formatted in any suitable way. A simple example will illustrate two suitable ways for formatting a cloud resource request. Let's assume the streams manager determines it needs two VMs, where both have common stream infrastructure, with a first of the VMs hosting operator A and the second of the VMs hosting operator B. The cloud resource request **540** in FIG. **5** could specify two VMs at **550**, could specify the common stream infrastructure, such as an operating system and middleware, at **560**, and could specify operator A and operator B at **570**. In response, the cloud manager would provision two VMs with the common stream infrastructure, with the first of the VMs hosting operator A and the second of the VMs hosting operator B. In the alternative, the cloud resource request **540** could be formulated such that each VM is specified with its corresponding stream infrastructure and stream application portion. In this configuration, the cloud resource request would specify a first VM with the common stream infrastructure and operator A, and a second VM with the common stream infrastructure and operator B.

Referring to FIG. **6**, a method **600** shows one suitable example for enhancing performance of a streaming application, and is preferably performed by the streams manager **360** interacting with the cloud manager **350**. The streams manager requests resources, such a VMs, from the cloud manager (step **610**). The cloud manager provisions the VMs (step **620**). The streams manager then deploys a portion of the flow graph to the VMs (step **630**). When the streaming application is not initially hosted in the cloud, the result will be a hybrid implementation of the streams application, with some portions

hosted on a dedicated computer system and other portions hosted by one or more VMs in the cloud.

FIG. **7** shows one suitable example of a more specific method **700** for enhancing performance of a streaming application. Note that method **700** could be one specific implementation for method **600** shown in FIG. **6**. The streams manager requests a specified number of VMs from the cloud manager with specified streams infrastructure and one or more specified streams application components (step **710**). The term "streams infrastructure" as used herein includes any software that is needed to run a component in the streaming application, such as an operating system and middleware that supports executing components in a streaming application. The term "streams application component" can include any component in a streaming application, including operators. The cloud manager provisions the VMs with the specified streams infrastructure and the one or more specified streams application components in response to the request from the streams manager (step **720**). The streams manager includes the VMs in the set of hosts available to the streaming application (step **730**). The streams manager then modifies the flow graph so one or more portions of the flow graph are hosted by the one or more VMs provisioned by the cloud manager (step **740**).

A simple example is provided in FIGS. **8** and **9** to illustrate some of the concepts discussed above. Referring to FIG. **8**, a streaming application **800** includes operators A, B, C, D, E, F, G, H, I and J as shown. Operator A originates a stream of tuples, which is processed by operator B, which outputs tuples. The tuples from operator B are processed by operator C, which outputs tuples to operator D, which processes the tuples and outputs its tuples to operator H. In similar fashion, operator E originates a stream of tuples, which is processed by operator F, which outputs tuples that are processed by operator G, which outputs tuples to operator H. Note that operator H receives tuples from both operator D and operator G. Operator H processes the tuples it receives from operator D and from operator G, and outputs its tuples to operators I and J. We assume for this example the streaming application **800** runs on a dedicated system, such as a computer system/server **100** shown in FIG. **1**.

The stream performance monitor **510** in FIG. **5** monitors performance of the streaming application **800** in FIG. **8** in accordance with one or more defined performance thresholds **520**. An example of a suitable performance threshold **520** is percent of capacity used. A performance threshold of say, 80% could be specified for operator F in FIG. **8**. Note a performance threshold can apply to a specified operator, to a specified a group of operators, or to all operators in the streaming application. We assume the streaming application **800** runs with operator F operating at less than 80% capacity, but due to increased demand, the performance of operator F grows to exceed **80%** capacity. In response to the performance of operator F exceeding the 80% defined performance threshold, the streams manager requests cloud resources to relieve the load on operator F. For example, the streams manager could request the cloud manager provision two VMs with streams infrastructure that supports running components of the streaming application and with the logic for operator F (step **710** in FIG. **7**). In response, the cloud manager provisions two VMs with the specified stream infrastructure and with the logic for operator F (step **720**). The streams manager includes the two VMs in the set of hosts available to the streaming application (step **730**). The streams manager then modifies the flow graph so one or more portions are hosted by the two VMs just provisioned (step **740**). The modifications to the flow graph are shown in the streaming application **900** in

FIG. **9** to include a new operator K and new operators F' and F" that implement the functions of operator F in two different virtual machines and that work in parallel with operator F. Note the new operator K is needed to split the tuples coming from operator E into three sets that are distributed to operators F, F' and F". Note that operators F' and F" are hosted on the virtual machines in the cloud provisioned by the cloud manager, as indicated by the VM in these operators, while operator F is hosted by a dedicated computer system that runs the rest of the streaming application **900** shown in FIG. **9**. The result is a hybrid system, with some operators in the streaming application **900** hosted on the dedicated computer system, with other operators, such as operators F' and F", hosted in the cloud.

While the simple example in FIGS. **8** and **9** shows two new operators F' and F" that implement the function of operator F, this is not to be construed as limiting of the concepts herein. Any suitable number of operators could be deployed in a single VM. For example, if performance of operators B, C and D all exceed one or more of the defined performance thresholds, a single VM could be provisioned with the logic for all of operators B, C and D. In addition, a VM could be provisioned to implement two different unrelated operators. For example, if operators C and F both exceed one or more of the defined performance thresholds, a single VM could be provisioned that implements both operator C and operator F. The disclosure and claims herein expressly extend to any number of virtual machines that implement any suitable number of operators.

Referring to FIG. **10**, a method **1000** is preferably performed by the streams manager **360**. When an operator in a VM is still needed (step **1010**=YES), method **1000** loops back and continues until the operator in the VM is no longer needed (step **1010**=NO). At this point the VM is destroyed (step **1020**), and method **1000** is done. In typical cloud environments, when a virtual machine is no longer needed, it is destroyed. This can be done in different ways. For example, a virtual machine could be destroyed, or could simply be marked for destruction, with a cloud maintenance mechanism actually performing the destruction during routine processing at a later time.

Destroying a VM as shown in FIG. **10** may not provide the best course of action. Referring to FIG. **11**, a method **1100** is preferably performed by the streams manager **360**. When an operator in a VM is still needed (step **1110**=YES), method **1100** loops back and continues until the operator in the VM is no longer needed (step **1110**=NO). The VM is then maintained in an active state (step **1120**). By maintaining the VM in an active state, the VM can be quick redeployed to implement the same operator, or to deploy a different operator, much more quickly than the time needed to provision and deploy a new VM.

Some suitable examples of active states are shown in the table in FIG. **12**. A first active state is to leave the input and output connected to the flow graph until the VM is needed elsewhere, as shown at **1210**. A second active state is to disconnect the input and output from the flow graph, as shown at **1220**. A third active state is to leave the input connected to the flow graph, but disconnect the output from the flow graph, as shown at **1230**. Note that in each of these active states, the VM is still running. Each of these active states in FIG. **12** is discussed in more detail below.

The first active state **1210** in FIG. **12** leaves the VM running and leaves the input and output connected to the flow graph until the VM is needed elsewhere. Thus, for the flow graph in FIG. **9**, we assume the streams manager determines the VMs implementing operators F' and F" are no longer needed. While not needed for performance reasons, they are left in the flow graph as shown in FIG. **9** with their inputs and outputs connected, and processing tuples until the streams manager determines the VMs that implement operators F' and F" are needed elsewhere. At this point the VMs will be deployed to a different part of the flow graph to address other performance issues.

The second active state **1220** in FIG. **12** leaves the VM running, but disconnects the input and output of the of the operator from the flow graph. For the flow graph shown in FIG. **9**, the second active state is shown graphically in FIG. **13**. We assume again the streams manager determines the VMs implementing operators F' and F" are no longer needed. The streams manager disconnects the inputs and outputs of the VMs implementing F' and F" from the flow graph, as shown in FIG. **13**, while keeping the VMs running. Should the VMs produce any tuples even though their inputs are disconnected, the tuples are discarded. Because the VMs are running, but are in a disconnected state, they can be easily reconnected to the flow graph as needed. In the alternative, they can be redeployed to a different part of the flow graph by the streams manager without having to request new virtual machines from the cloud manager.

The third active state **1230** in FIG. **13** leaves the VMs running, but disconnects the output of the operator from the flow graph. For the flow graph shown in FIG. **9**, the third active state is shown graphically in FIG. **14**. We assume again the streams manager determines the VMs implementing operators F' and F" are no longer needed. The streams manager disconnects the outputs of the VMs implementing F' and F" from the flow graph while keeping the inputs connected and the VMs running, as shown in FIG. **14**. Note the streams manager will change the logic of operator K when the VMs for F' and F" have their outputs disconnected. Instead of splitting the tuples between F, F' and F" so these three process different tuples in parallel, operator K will route all of the tuples to each of F, F' and F". The tuples produced by the VMs that implement F' and F" are discarded. Because the VMs are running, but are in a disconnected state, they can be easily reconnected to the flow graph as needed. In the alternative, they can be redeployed to a different part of the flow graph by the streams manager without having to request new virtual machines from the cloud manager. Note that redeploying may require waiting until all tuples in-flight have finished processing. In addition, the third active state **1230** has the added advantage of actively processing tuples in parallel with the original operator F. This allows the VMs that implement F' and F" to be quickly reconnected into the flow graph with very little lag because they are already actively processing tuples. In addition, should operator F have a problem or go down altogether, the tuples operator F was processing are also being processed in parallel by F' and F", so the streams manager may be able to recover from operator F crashing without missing any data by using the data that was being processed in parallel by F' and F".

Note the active states shown in FIG. **12** are shown by way of example. Other active states could also be used. The active states are not mutually exclusive. The streams manager can use any active state or any suitable combination of active states for different flow graphs or for different operators in the same flow graph. For example, the streams manager could maintain a first virtual machine in a flow graph in the first active state **1210**, could maintain a second virtual machine in the same flow graph in the second active state **1220**, and could maintain a third virtual machine in the same flow graph in the third active state **1230**. The disclosure and claims herein expressly extends to using any suitable active state or combination of active states for virtual machines that implement streaming operators in a flow graph.

The disadvantage of keeping virtual machines in an active state is the use of virtual machine resources even though their use from a performance standpoint is not currently needed. The advantage of keeping the virtual machines in an active state is these VMs can be easily and readily redeployed to a different part of the flow graph by the streams manager without having to request new virtual machines from the cloud manager. Because streaming applications process data in near real-time, the advantage of keeping virtual machines that implement streaming operators in a ready state so they can be quickly and efficiently redeployed can often outweigh the cost.

The streaming application disclosed and claimed herein provides an incredibly powerful and flexible way to improve the performance of a streaming application. A dedicated computer system can include minimal resources that can run the streaming application at periods of low demand, while allowing the capacity of the streaming application to be automatically expanded using cloud resources as needed. Keeping virtual machines in a ready state allows these virtual machines to be used by the streams manager without the overhead of deploying a new virtual machine. This provides a very powerful and cost-effective solution to running streaming applications.

The disclosure and claims herein relate to a streams manager that monitors performance of a streaming application, and when the performance needs to be improved, the streams manager automatically requests virtual machines from a cloud manager. The cloud manager provisions one or more virtual machines in a cloud with the specified streams infrastructure and streams application components. The streams manager then modifies the flow graph so one or more portions of the streaming application are hosted by the virtual machines in the cloud. When performance of the streaming application indicates a virtual machine is no longer needed, the virtual machine is maintained and placed in a ready state so it can be quickly used as needed in the future without the overhead of deploying a new virtual machine.

One skilled in the art will appreciate that many variations are possible within the scope of the claims. Thus, while the disclosure is particularly shown and described above, it will be understood by those skilled in the art that these and other changes in form and details may be made therein without departing from the spirit and scope of the claims.

The invention claimed is:

1. A computer-implemented method executed by at least one processor for managing a streaming application, the method comprising:

executing a streaming application that comprises a flow graph that includes a plurality of operators that process a plurality of data tuples;

monitoring performance of the streaming application;

when performance of the streaming application needs to be improved, requesting a cloud manager to provision at least one virtual machine with logic to implement at least one of the plurality of operators;

after the cloud manager provisions the at least one virtual machine, modifying the flow graph to include the at least one virtual machine in the flow graph of the streaming application; and

when performance of the streaming application no longer needs to be improved, keeping the at least one virtual machine in a ready state until the at least one virtual machine is needed to implement at least one of the plurality of operators, wherein the ready state comprises a first state where each of the at least one virtual machine runs with an input of an operator implemented by the virtual machine connected to the flow graph and an output of the operator disconnected from the flow graph.

2. The method of claim **1** wherein the ready state comprises a second state where each of the at least one virtual machine runs with an input and an output of an operator implemented by the virtual machine connected to the flow graph.

3. The method of claim **1** wherein the ready state comprises a third state where each of the at least one virtual machine runs with an input and an output of an operator implemented by the virtual machine disconnected from the flow graph.

4. The method of claim **1** further comprising reusing the at least one virtual machine in the ready state by deploying the at least one virtual machine to implement at least one of the plurality of operators.

5. The method of claim **1** wherein the monitoring the performance of the streaming application compares current performance of the streaming application to at least one defined performance threshold.

6. The method of claim **5** wherein, by comparing the performance of the streaming application to the at least one defined threshold, a determination is made when the performance of the streaming application needs to be improved.

7. The method of claim **1** wherein the at least one virtual machine implements logic for a selected one of the plurality of operators, wherein the at least one virtual machine processes tuples in parallel with the selected one operator in the flow graph after the streams manager modifies the flow graph of the streaming application.

8. The method of claim **7** further comprising modifying the flow graph to include a new operator that splits tuples from an existing operator to the selected one operator in the flow graph and to the at least one virtual machine that processes the tuples in parallel with the selected one operator in the flow graph.

9. A computer-implemented method executed by at least one processor for managing a streaming application, the method comprising:

executing a streaming application that comprises a flow graph that includes a plurality of operators that process a plurality of data tuples;

monitoring performance of the streaming application;

determining when performance of the streaming application needs to be improved by comparing the current performance of the streaming application with the at least one defined performance threshold;

requesting a cloud manager to provision first, second and third virtual machines that each include logic to implement one of the plurality of operators;

after the cloud manager provisions the first, second and third virtual machines, modifying the flow graph to include the first, second and third virtual machines in the flow graph of the streaming application;

when performance of the streaming application no longer needs to be improved:

keeping the first virtual machine in a first ready state where the first virtual machine runs with an input and an output of an operator implemented by the first virtual machine connected to the flow graph;

keeping the second virtual machine in a second ready state where the second virtual machine runs with an input and an output of an operator implemented by the second virtual machine disconnected from the flow graph; and

keeping the third virtual machine in a third ready state where the second virtual machine runs with an input of an operator implemented by the second virtual machine connected to the flow graph and an output of the operator disconnected from the flow graph.

* * * * *